00HQGR0052

EARTHQUAKE PROBABILITIES, CYCLES, AND HAZARDS IN NORTHERN CALIFORNIA: A SYNTHETIC SEISMICITY APPROACH

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TECHNICAL ABSTRACT

Earthquakes interact in the sense that stresses shed from a fault during one event either advance or delay the occurrence of nearby earthquakes. Many researchers have applied this concept to the faults of the San Francisco Bay Area by mapping areas of stress enhancement or stress shadow caused by historical earthquakes. Due to the region's closely spaced, sub-parallel distribution of faults, earthquakes of the San Francisco Bay are likely to be more strongly affected by fault stress interaction than earthquakes in any other place in the world. Given this, I believe that meaningful progress toward updating the *WGCEP/90* probabilities can be made only with the guidance provided by physically-based and region-wide earthquake simulations. As a first step toward realizing a *Standard Physical Earthquake Model* for the San Francisco Bay Area, this project offered a set of seismicity simulations. These simulations demonstrate the feasibility of a *Standard Physical Model* and they blueprint its construction. The quasi-static earthquake simulations fielded herein resemble those originally developed for use in southern California (*Ward*, 1996), however the newer models incorporate several improvements in the theoretical formulation including:

1) Allowance for a finite speed of signal propagation (v_p) while keeping within a quasi-static framework.
2) Association of a specific intra-seismic interval (dt) with each step in the rupture simulation.
3) Incorporation of fully localized fault friction.
4) Formation of explicit relationships among critical slip velocity, critical slip distance, and critical patch size for run-away failure in terms of v_p, dt and the difference between static and dynamic fault strengths.

These improvements enable three primary extensions to previous efforts in this field:

- The timing and slip distribution of earthquakes are not specified by the user, but rather earthquakes occur spontaneously. Fault strength, fault friction law, and the existing state of stress solely determine the timing and extent of earthquake ruptures.

- Stress states are considered not only before and after earthquakes, but within each earthquake as well. This model generates detailed rupture histories from nucleation to healing.
- Applied interseismic stresses are not uniform. Instead, variable tectonic stresses drive each fault in the system at a velocity compatible with its estimated geological slip rate.

Physical earthquake models represent the best existing means to quantify earthquake recurrence in a region characterized by closely spaced, sub-parallel faults. Physical models serve as a platform for: 1) data utilization and verification, any earthquake statistic that is measurable in the field or in the laboratory can be compared directly with, and used to tune and test seismicity model products; 2) probability forecasts, a physical earthquake model supplies rational estimates of every imaginable earthquake statistic while simultaneously satisfying all slip and earthquake rate constraints; and 3) hazard analysis, a physical earthquake model catalogs suites of detailed rupture scenarios for every fault in the system. Convolving these slip histories with site-specific dislocation Green's functions produces a full set of shaking time-series at any desired position. Probabilistic estimates of shaking intensity can be constructed directly from this set of synthetic seismograms without need for empirical attenuation relations.

NON-TECHNICAL ABSTRACT

Earthquakes in California's San Francisco Bay Area are likely to be more strongly affected by elastic stress interaction than earthquakes in any other place in the world because of the region's closely spaced, sub-parallel distribution of faults. Meaningful progress in quantifying earthquake probability and hazard in the Bay Area can be made only with the guidance provided by physically-based and region-wide earthquake models that account for this interaction.

This project made a first step in developing a *Standard Physical Earthquake Model* for the San Francisco Bay Area through realistic, simulations of earthquakes on all of the area's major faults. Physical earthquake models have advanced greatly in the last decade. This project has shown that a *Standard Physical Earthquake Model* is entirely feasible, it illustrated how such a model could be applied, and it blueprinted the model's construction. A *Standard Physical Earthquake Model* as developed here provides the mechanism to integrate fully the diverse disciplines within the earthquake research community.

- As a platform for data utilization and verification, a physical earthquake model can employ directly any earthquake property that is measurable in the field or in the laboratory to tune and test its seismicity products.

- As a platform for probability forecasts, a physical earthquake model can supply rational estimates of every imaginable earthquake statistic while simultaneously satisfying all slip and earthquake rate constraints.

- As a platform for hazard analysis, a physical earthquake model can compute earthquake-shaking intensity from first principles by convolving a full suite of rupture scenarios with site-specific dislocation Green's functions.

The absence of a catalog of observed seismicity that spans many earthquake repetition intervals is a fundamental stumbling block to earthquake prediction in California. Seismologists just do not have a long enough historical record to make statistically justifiable conclusions about most earthquake recurrence behaviors. Conceding that this limitation in the observational catalog is not likely to go away in the foreseeable future, alternative approaches must be sought. Simulations of earthquake generation and recurrence are now sufficiently credible that such calculations can begin to take substantial roles in scientific studies of earthquake probability and hazard.

This project constructed a plausible synthetic seismicity model for the major faults of northern California and exploited the catalog to refine estimates of San Francisco Bay Area earthquake recurrence patterns, probabilities, and ground shaking hazard.